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Case Study of the Evaluation and Verification of a PackBot Model in NRMM

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ABSTRACT

The NATO Reference Mobility Model (NRMM)[1] is the primary mobility software used by the US Department of Defense, its contractors and NATO countries to evaluate various metrics of proposed vehicle systems for acquisition. The NRMM is a vehicle mobility performance model developed in the 1970's[2] that combines mobility related technologies into one comprehensive software package designed to predict the physically constrained vehicle and terrain interaction while operating in both on and off road environments. The empirically based relationships within NRMM are measurements taken from actual vehicles run over a variety of terrains and are geared towards vehicles weighing more than 1500 pounds. As the Army focuses on a lighter, faster and more mobile fighting force, standard military vehicles are decreasing in size with many new ultra lightweight autonomous systems being designed. This fundamental shift in the size and weight of military vehicle systems, questions, the NRMM predictions for on and off road performance. The following paper describes a case study comparing NRMM predictions of the current Future Combat System (FCS) Small Unmanned Ground Vehicle (SUGV), This paper defines required extensions in the existing data fields for the terrain and vehicle to support predictions of SUGV's in NRMM.

INTRODUCTION

The NATO Reference Mobility Model (NRMM) was developed to evaluate vehicles over various types of terrain. The software was developed in the 1970's through thirty years of extensive testing of various military vehicle platforms in the field. With these tests, various relations were developed for the interaction of wheeled and tracked vehicles on soft soil [3]. The software provides insight into vehicle comparisons over various types of soils, roads, and obstacles within the larger theater of a battlefield scenario with different weather conditions and terrain maps. These comparisons are important to gain a numerical assessment of a vehicle's capability for design and comparison over various terrains. It gives a tangible and uniform method for evaluating several proposed vehicles' performance through prospective battle zones and also gives contractors a starting point for their design process.

Currently, the NRMM is used in the vehicle procurement process to qualitatively compare vehicles for acquisition. It is a simple tool that can be easily used for wheeled and tracked vehicles ranging from 1 to 70 tons to provide a comparison of performance on varied terrains. The inputs required are the geometry of the vehicle, general ride characteristics, and the desired scenario including terrain and weather information. The NRMM is also used as a guide to improve designs by providing information on how well a vehicle traverses a terrain for a specific mission. It has also been imbedded in several war gaming simulation models, as well as a component in many Army tactical decision aid applications [4] and is one of the standard modeling and simulation programs used.

Historically, the typical vehicles evaluated with the NRMM range from a vehicle that is capable of carrying one passenger and a payload to vehicles as large as can still travel on roads and fit under bridges. Examples of vehicles from these categories is the M151 Jeep (about 1 ton) to the M1 tank (about 70 tons). The vehicles used in this analysis to provide a comparison of the software are the M151A2 and HMMWV.

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Figure 1: Comparison of Vehicles

One of the components of running a vehicle simulation is to place the vehicle in a terrain situation. Some of the typical scenarios included with the software are Germany, Korea, and the Mid-East. The terrains were created from tactical terrain databases and have a resolution of 100 meters. They are based on actual gathered terrain data from a specific location with additional data added to provide a statistically accurate description of areas typical to that area. For instance, one of the components of the terrain file is the spacing of tree stems of various diameters. It was determined from field data, relationships between stem diameter and spacing follow a Weibull [5] distribution. Inference routines are used to complete the terrain picture. There are five maps overlays used to define the off-road terrain. These include elevation, land usage, vegetation, obstacles,, and soil information. Within these different categories are classes- ranges of appropriate dimensions. As an example, vegetation is broken down into cumulative classes of diameters for stems. Class 2 contains stems greater than 2.5 cm diameters, Class 3 has stems greater than 6.0 cm diameters, and going up to Class 8 for stems greater than 25 cm diameters.. This assumes that trees 25 cm in diameter impede all wheeled and tracked vehicles, similarly. Likewise the classing system assumes trees less than 2.5 cm can be grouped into the same class. The force require to override this vegetation is calculated based on the number of stems within the class relative to the width of the vehicle.

NRMM algorithms compute forces and constraints used to determine speed-made-good and go/no-go for a defined set of tactical mission scenarios. Speed-made-good is defined by the NRMM users guide as the effective maximum vehicle speed from one given location to another. Other results available in the output file include the main limiting factors for the speed,. Typical limiting factors for the larger vehicles simulated in the NRMM are power, geometry issues (maneuvering, obstacle clearance, etc.), ride and shock capabilities, braking capabilities, and soft soil issues.

EVALUATING THE PACKBOT WITH NRMM

The PackBot is a man-packable robot from iRobot used by the Army for surveillance missions. It was most recently deployed in the caves of Afghanistan for reconnaissance and is currently being used in Iraq to help soldiers remotely examine improvised explosive devices. It is a telemetry operated durable robot designed to climb stairs, and be thrown into a building, cave, etc. to perform its mission.

While there are obvious differences between a 45 *ton* tank and a 45 *pound* PackBot, using smaller vehicles and scaling up the forces are the genuses for many of the existing algorithms in NRMM [6]. The issues become the need for higher terrain resolution to support the vehicle predictions. Earlier versions of NRMM [2] did not predict for obstacles less than 4 inches high. The resolution and number of classes of vegetation must be increased to support predictions of the movement of the smaller vehicles.

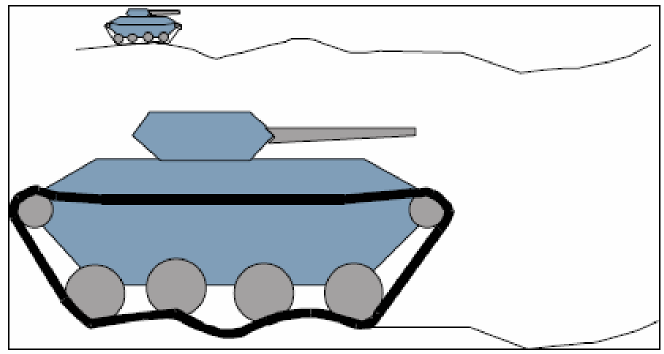

Figure 2: Small Lightweight Vehicle Crossing a Given Terrain vs. Large Heavy Vehicle

Another component of the NRMM is the consideration of a driver. The code limits the vehicle's top speed based on comfort levels for the driver. An autonomous or tele-operated vehicle prediction will replace driver discomfort with component failure as a primary mobility limiting factor. NRMM incorporates a shock analysis based on a single obstacle impact subject to a limiting factor in its VEHDYN submodule. Also included in the module is a ride limiting criterion based on the continuous vibration due to surface roughness and peak g's due to discrete obstacles. From these criteria, there is a resultant driver "comfort" range that forces limitations in the speed of the vehicle. In PackBot's case, it is a teleoperated tracked vehicle and is not necessarily bound to a driver comfort regulated speed, but there are limitations that could be limitations placed on the vehicle based on instrument sensitivity or sensor degradation. For instance, the tele-operator may slow down the vehicle if the camera image is moving too fast for the remote images to be seen clearly. Constraints due to communication with the vehicle will be introduced.

With all of the complications involved in evaluating a small, lightweight vehicle platform with the NRMM, one might ask why use the software at all? The NRMM is the one of the only software package that evaluates a vehicle in a battlefield scenario [7]. It is an important software package that is more comprehensive than most of the similar packages because it takes into account ride, shock, soft soils, slope climbing, visibility, etc. in the simulations simultaneously.

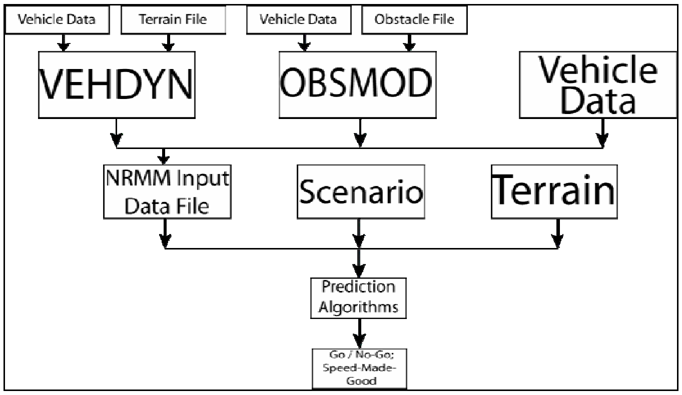

Figure 3: NRMM Program Flow

To begin running the PackBot model in NRMM, it is important to get an accurate picture of the geometry. Many measurements of the PackBot were taken. Some of the measurements involved the center of gravity location and the equilibrium forces under the contact points. Some examples of the measurements needed are provided in Figures 4 and Figures 5.

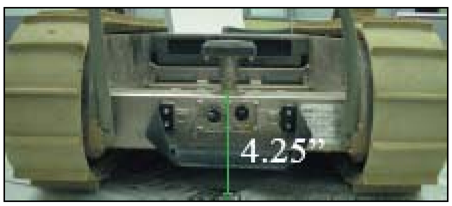

Figure 4: Height of Hitch from Ground

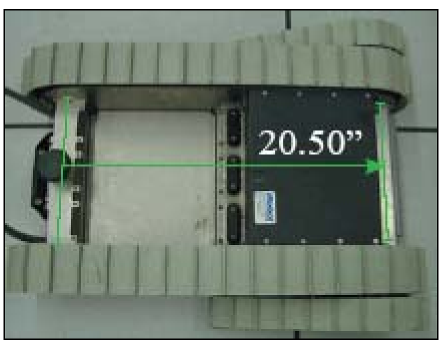

Figure 5: Horizontal Position of Support with respect to Hitch

Once the geometry information was complete, the next step was to run the model through the preprocessor, OBSMOD. The OBSMOD module runs the vehicle over a series of obstacles that can be specified by the user through the obstacle file. The obstacle file specifies the height, angle of approach, and the length of the obstacle. The program assumes the obstacle is symmetrical.

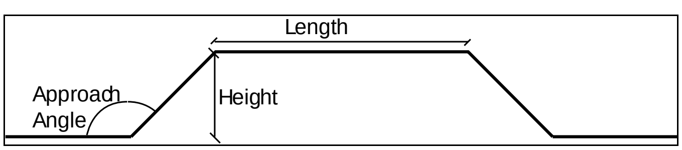

Figure 6: OBSMOD Obstacle Description

The obstacle file is just one of the components of running OBSMOD. The other key component is the input file which lists all of the different geometric information. One of the issues with the OBSMOD code is that even though it is able to deal with tracked vehicles, the program does not recognize that there is a track band connecting the road wheels. Modifications to the program were made to model a tracked system. There was no suspension system on the Packbot. The tracks acted to dampen the vehicle to shocks, therefore damping components were incorporated into the track model.

The flippers of the robot were a unique challenge. Due to the flippers, the robot is capable of being put into a series of different configurations that affect the mobility of the vehicle. For the tests conducted in this paper, the flippers were placed at 0, 45, 90, and 180 degrees. (see figure 7).

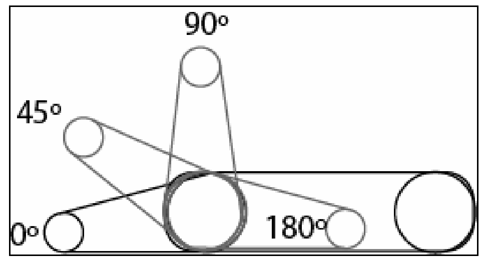

Figure 7: PackBot's Flipper Positions for Trials

Based on the angle of the flippers several different aspects of the input file needed to be changed, such as the number of road wheels, the center of gravity position, and the equilibrium points. The flippers also added to the complication of how to define something as simple as the width of the vehicle.

Figure 8: Tread Widths and Minimum Widths Between Traction Elements

The outputs of the OBSMOD module are the minimum clearance height of the vehicle (a negative signifying that the robot would encounter interference while negotiating the obstacle), the maximum tractive force, and the average tractive force. Once all of the files were run, the final results were compiled into a best overall file. The flippers can be adjusted on the fly so it makes sense that during a run, the robot’s flippers could be changed to get the best mobility out of the system.

After the best OBSMOD file is compiled, the results are appended to the end of the input file for the NRMM program. Along with the OBSMOD file, other geometry information is necessary as well as some of the same information from the OBSMOD input file. Some of the additional information necessary is the driver’s eye height above ground (for this case, the camera height above ground), grouser height, and area of track shoe.

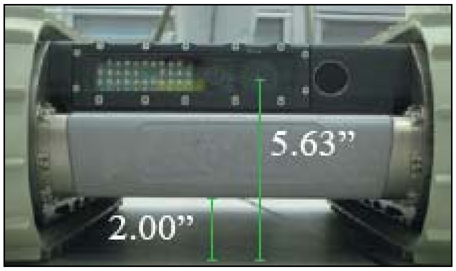

Figure 9: Minimum Ground Clearance and Driver's Eye Height Above Ground

Again, it is not always clear what measurements to use. To make sure the model is working appropriately, a check out terrain is used. This is a fictitious terrain concocted to give an intuitive check for known go and no-go situations. For instance, if there is a densely packed area of large diameter stems then, that area is no-go. The information in the off-road terrain file able to be manipulated falls into two categories: soil / surface geology and obstacle information. Soil / surface geology lists the soil type, land usage (agriculture, forest, etc.), wetness index, soil strength for upper and lower layers (first 12” of soil) for the wet and dry seasons in terms of the vehicle cone index (VCI), slope and surface roughness (root mean square evaluation). The obstacle portion lists the approach angle, height, base width, spacing, type of spacing, average stem spacing, and visibility for the different seasons. The check-out terrain file was scaled by adjusting the various obstacle descriptors listed above (approach angle, height, etc.) to accommodate soil characteristics and obstacles that would affect the mobility of the vehicle.

The last component necessary for vehicle analysis in NRMM is VEHDYN. Many times this submodule can be replaced directly with shock and ride data from field tests and is often done so. VEHDYN can also be used to get information about the obstacle crossing capability of the vehicle. All of the parametric results generated by VEHDYN and OBSMOD are necessary for the NRMM program to provide ride, shock and obstacle performance estimates, This information can be gathered in various ways and from a variety of sources including more detailed industry standard general purpose mechanical system simulation codes.

PACKBOT NRMM ANALYSIS

The results summary file is a concise snapshot. Sifting through the data files reveals a picture of what the software is doing. Namely, the final summary output is path independent while inside the program there is information regarding the go/no-go percentage of slopes depending on whether it is an up-slope, down-slope or side-slope, as well as information on the controlling factors for why the vehicle had a no-go. If a vehicle has a no-go on an up-slope but a go on the equivalent down-slope, then for that terrain patch, the vehicle will have an overall no-go. The program does an equal distribution of terrain patches with up-slopes, down-slopes and side-slopes to take this into account.

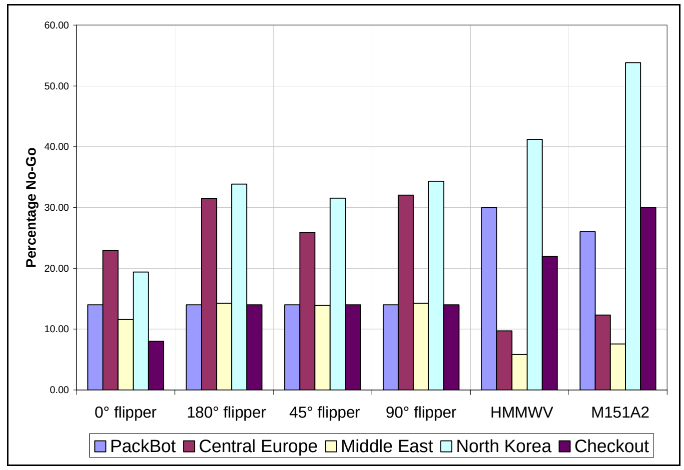

Figure 10: No-Go Percentages for Various Scenarios

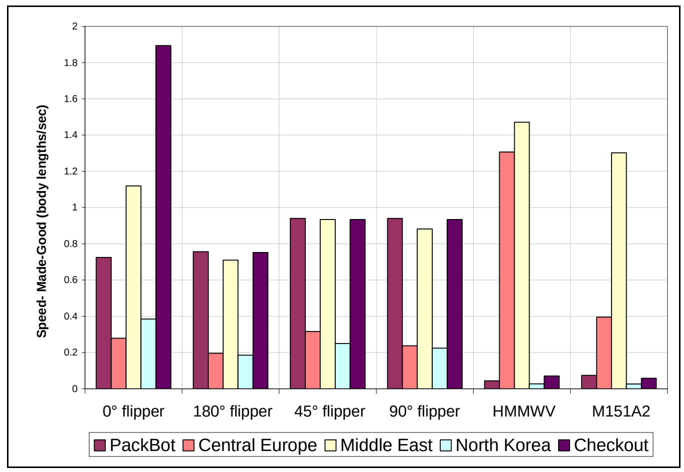

Figure 11: Speed-Made-Good for Various Scenarios over 90% of Terrain

The only flipper position that appears to make a difference in the speed of the vehicle is 0 degrees (flippers fully extended), except for the PackBot checkout terrain. With the flippers fully extended there is more ground contact and therefore more traction. One issue with the results is an overall no-go reason for the PackBot in some of its various configurations (180°, 45°, and 90°). Typically this happens when the obstacles are out of range of the initial observations through OBSMOD. Since the obstacles were scaled down in OBSMOD, the results should be rerun to take into account other larger obstacles typically found in the specific terrains. Other reasons for no-go’s for the PackBot were vegetation and obstacle override problems (the PackBot could not overcome these items). For the HMMWV and M151A2, the main no-go reason was obstacle clearance- the vehicle would get stuck on an obstacle. In looking at the results from the speed-made-good on 90% of the terrain, the PackBot did well in comparison to the other vehicles when the information was normalized to body lengths per second. The HMMWV still has the advantage over all of the vehicles for overall speed in the Central Europe and Middle East terrains, with the M151A2 close behind.

	PB,0º	PB, 180º	M151	HMMWV
Soil	0.5	0.5	4.5	4
Veg	5	5	7	6
Obst	0	0	0	0
Other	-	-	-	4*****

Table 1: NO-GO Performance for Scaled Check-Out Terrain

*****Side slope (a soil limit) was not considered for the PackBot or the M151

	PB,0º	PB, 180º	M151	HMMWV
Soil	1.3	0.3	4.7	4.3
Veg	0	0	2	2
Obst	2	0	7	2
Other	-	6******	-	2*****

Table 2: Percent NO-GO Performance for "Normal" (Unscaled) Check-Out Terrain

*****Side slope (a soil limit) was not considered for the PackBot or the M151
******Incomplete obstacle performance analysis

It should be noted that neither of these terrain data sets represent an actual operational area; each of these data sets is comprised of 50 arbitrarily chosen terrain descriptions representing a wide range of terrain attribute values. The “scaled” terrain is similar to the “typical” NRMM checkout terrain but with obstacles reduced in size (shorter than the default 4” height) to attempt to enhance sensitivities of the smaller PackBot. For the statistics presented in this paper, each of these terrain representations has been assigned unity area. Since there are 50 samples, each sample represents 2% of the total set.

The above tabulations indicate that the PackBot provides better soft-soil performance than the “traditional” vehicles. This is as expected due to the unusual low contact pressure of the PackBot. Since the PackBot has no frame protrusions beyond its tracks, no obstacle interference was expected; the PackBot results align with this expectation. Vegetation performance is mixed as the reduced (almost nonexistent) override capability if the PackBot is offset by its greatly increased maneuverability due to its small size. It should be noted that this is an extremely limited data set.

Future work should include developing a terrain data set that better depicts the vehicle sensitivities, the establishment of mission profiles in order to provide mission related statistics, and the identification of “base-line” vehicle of similar size with known mobility performance capabilities.

EXPERIMENTAL WORK

In order to verify the results gathered from the NRMM test data with those of the actual PackBot, there were a number of pull-bar tests done on the vehicle over four different types of surfaces- cement, sand, gravel, and grass. The preliminary results for the simple pull-bar tests show an average pull-force of around 27 lbf (120 N).

Figure 12: PackBot Experimental Testing Materials

Starting at the upper-left corner and proceeding clockwise, the images in Figure 12 show the various materials the PackBot was tested on like sand, grass, gravel, and the coated cement.

FUTURE WORK

Further work needs to be done to correlate the experimental test situations to a user-generated terrain to verify the correlation between NRMM and the physical robot. Additionally, tests regarding the PackBot’s performance over obstacles can be performed to test the fidelity of the lightweight vehicle in the OBSMOD submodule through measuring the maximum and average tractive forces over man-made obstacles which can be created in the parametric terrain input file.

Another aspect that would aid in developing better models for the small robotic platforms is to determine more precise mission scenarios. Providing mission scenarios gives the group a better idea of what the robot is attempting to accomplish and a more descriptive image of what the test terrain should look like.

CONCLUSION

NRMM has potential for use as a design and evaluation tool for the assessment and suitability of small robotic vehicles. Through the study, the NRMM’s sensitivities to smaller robots were revealed. The biggest ‘obstacle’ for its broad use as an evaluation tool is the lack of mapped terrain of suitable fidelity and the lack of definition of small vehicle operational missions. As the operational missions become more complete, the NRMM can provide a more holistic picture of the robot in a terrain/scenario sensitive mission. Unfortunately, the

NRMM will still be limited in its sense of the complete mobility package of a robot configured any differently from a traditional tracked or wheeled vehicle, without some amount of creativity. Even with the PackBot's flippers there were many complications and decisions to make. In general though, the NRMM will be able to give a snapshot of a robot's capabilities that will be good for use in comparisons among similar locomotive platforms.

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